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UPWASH CHARACTERISTICS AT SEVERAL STATIONS ON A BLUNTED CONE-FRUSTUM-CYLINDER MODEL AT MACH NUMBERS FROM 1.60 TO 4.65

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SUMMARY

An investigation of the upwash characteristics at several longitudinal stations along and above the surface of a blunted cone-frustum-cylinder model has been conducted in the Langley Unitary Plan wind tunnel. Data were obtained over a Mach number range from 1.60 to 4.65 at Reynolds numbers from approximately 2×10^6 to 4×10^6 per foot depending on the Mach number. The data are presented as variations in upwash factor, defined as the slope of the local flow angle to the model angle of attack. Some of the effects of yaw angle, longitudinal station, and distance above the surface on the upwash factor are shown.

INTRODUCTION

In many instances, aerodynamic heating precludes the use of boom-mounted sensing devices for missile applications. For these cases, it is, therefore, desirous to examine the feasibility of body-mounted systems. The present investigation is the result of interest in a pressure-type angle-of-attack sensor mounted in this manner.

Obviously, an indicator with a calibration entirely insensitive to yaw and Mach number would be most desirable. However, any probe of practical length will be subjected to upwash and sidewash effects dependent on Mach number. Consequently, the evaluation of a body-mounted angle sensor reduces to the problem of locating a position on or near the surface where these effects are minimized.

In the present study, a null-balance, slotted pressure probe was utilized to determine the upwash characteristics at several longitudinal stations along a blunted cone-frustum-cylinder model. Measurements of local flow angle were obtained at Mach numbers from 1.60 to 4.65 for a range of angle of attack and sideslip from -10° to 8° and -9° to 9°, respectively. These measurements were reduced to an upwash factor which is presented at four longitudinal stations along the body at five distances outward from the surface.

COEFFICIENTS AND SYMBOLS

d	distance outward from and perpendicular to surface, in.
M	free-stream Mach number
R	radius
α_i	local indicated flow angle, deg
α_m	angle of attack referenced to model center line, deg
β	angle of sideslip referenced to model center line, deg
ϕ	upwash factor, slope of local flow angle to model angle of attack, $d\alpha_i/d\alpha_m$
$\frac{d\phi}{d\beta}$	rate of change of upwash factor with sideslip angle, evaluated for $\Delta\beta = \pm 4^{\circ}$

APPARATUS AND MODEL

Tests were conducted in both the high and low Mach number test sections of the Langley Unitary Plan wind tunnel. This tunnel is of the variable-pressure, continuous-flow type with test sections 4 feet square and approximately 7 feet long. Leading to each test section is an asymmetric sliding block nozzle which permits the Mach number to be varied from 1.5 to 2.8 in the low Mach number section and from 2.3 to 4.7 in the high Mach number section without tunnel shutdown.

The model consisted of a nose of an arbitrary radius, two conical frustums, and a cylindrical afterbody. A sketch of the model is presented in figure 1. A sting connected to the rear of the afterbody provided the means of attaching the model to the central support system of the tunnel. Included in this support system was a remotely operated, adjustable angle coupling which permitted variations in angle of attack at various sideslip angles. Photographs of the model mounted in the tunnel are shown in figure 2.

In order to measure the local flow angle, a cylindrical probe with two slots 90° apart was mounted perpendicular to the surface of the model at stations 1 to 4. Details of the probe can be seen in figure 1. Outward extension of the probe from the surface (positions A to E) and its rotation about the longitudinal axis were electrically recorded. The slots of the probe were ducted to a differential pressure transducer, the output of which was connected to a null-balance meter. At each test point the probe was rotated until the pressure signal was nulled and the readings of the probe extension and rotation meters were recorded. These readings were then converted by means of suitable calibration curves to local flow angle and to the distance outward from the surface (in inches). A more complete description of the probe and its operating equipment is given in reference 1.

TESTS

The present study was conducted over an angle-of-attack range from -10° to 8° for sideslip angles from -9° to 9°. Two probes located at different longitudinal stations (for example, at 1 and 3) and 180° apart were installed in the model. By relocating these probes at two other stations (at 2 and 4), four longitudinal stations, each having five outward distances from the surface, were investigated.

The test conditions are listed in the following table:

Mach number	Stagnation pressure, lb/sq in.	Stagnation temperature, °F	Dynamic pressure, lb/sq ft	Reynolds number per ft
1.60	14.7	125	892.37	3.92×10^{6}
2.00	14.7	125	757.58	3.38
2.49	15	150	557.57	2.56
2.98	15	150	378.29	1.98
3.83	40	150	489.02	3.38
4.65	40	150	248.83	2.30

The dewpoint temperature for all the tests was maintained below -30° F to prevent adverse condensation effects.

CORRECTIONS AND ACCURACY

No corrections have been applied to the data for stream angularity. In order to minimize this angularity throughout the test, the model was kept at the same longitudinal station and was restricted to a vertical travel of less than 2 inches. Consequently, any flow angularity that existed provided a constant increment to the model angle of attack and, hence, affected only the level of the measurement and not the slope or upwash factor.

Angles of attack and sideslip have not been corrected for sting deflection. However, computations employing unpublished small-scale results for the tested model geometry indicate that the maximum sting deflection should be less than 0.3°. Since most test conditions represent considerably less load than the maximum, it is believed that the error due to deflection is less than that caused by other factors. In any event, this error is always such that the absolute value of the actual model angle of attack is greater than the nominal value set by the tunnel operator. Consequently, because of this error, the values of the upwash factor presented are always larger than the actual upwash factor that exists (believed to be of the order of 2 percent or less).

The estimated accuracy of the various items of the tests is as follows:

Mach number	± 0.02
α_m or β, deg	± 0.2
α_i, deg	± 0.1
ϕ	± 0.03

PRESENTATION OF RESULTS

An abbreviated outline of figure content is presented as follows:

	Figure
Typical variations of α_i	3
Schlieren photographs at various Mach numbers	4
Effect of β, station, and M on variation of ϕ with d . . .	5
Variation of $d\phi/d\beta$ with M	6

After the individual probe rotations were reduced to local flow angles, these angles were plotted against their respective model angles of attack. (See, for example, fig. 3.) It was found that, within the accuracy of the data, a linear curve was appropriate to describe the upwash variations. Hence, the basic results of the tests are presented as variations in the slope ϕ or upwash factor and are contained in figure 5. Cross plots of the variation of upwash factor with sideslip angle were made from these basic data. The slopes of these cross fairings were then evaluated for a range of β from -4° to 4° and are plotted against Mach number in figure 6.

It is to be noted that the signs of $d\phi/d\beta$ for stations 1 and 2 should be reversed when compared with the results at stations 3 and 4. This is necessary so that the variations of $d\phi/d\beta$ for all stations will be consistent with respect to windward and leeward sides of the model.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., May 22, 1959.

REFERENCE

1. Holderer, Oscar C.: Measurement of the Upwash Factor on a Cone-Cylinder Model. Rep. Nr. DA-R-11, Dev. Operations Div., Army Ballistic Missile Agency (Huntsville, Ala.), June 1957.

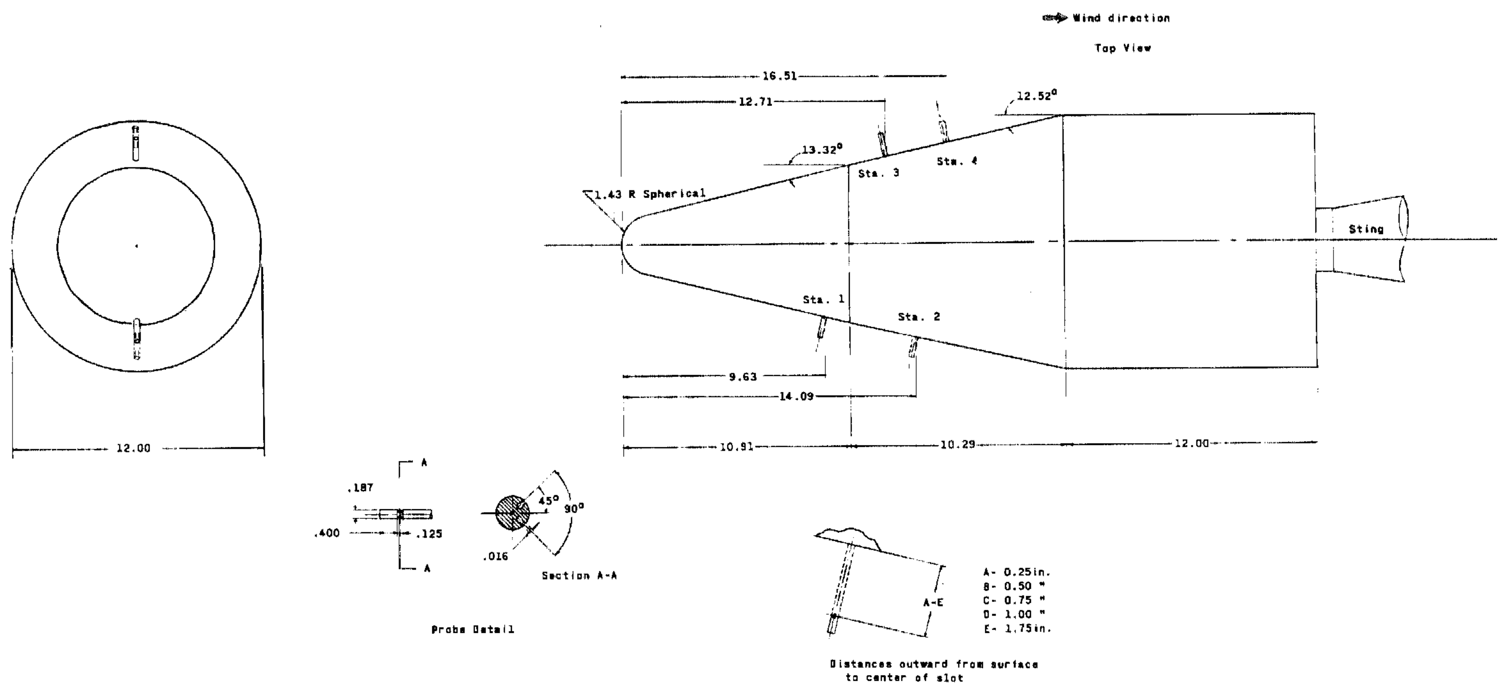


Figure 1.- General arrangement of upwash survey model. All dimensions are in inches unless otherwise specified.

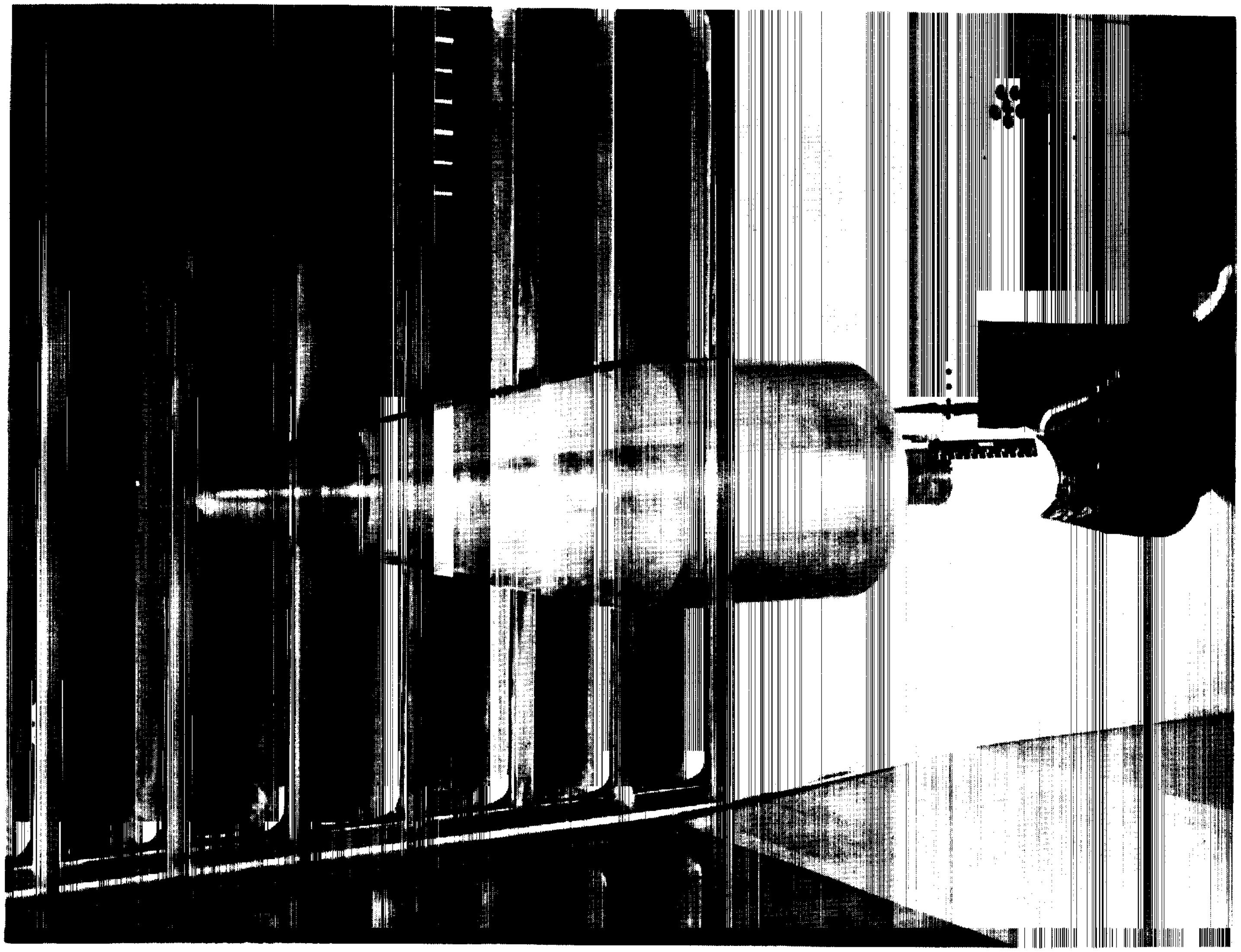


Figure 2.- Model photographs. L-57-699

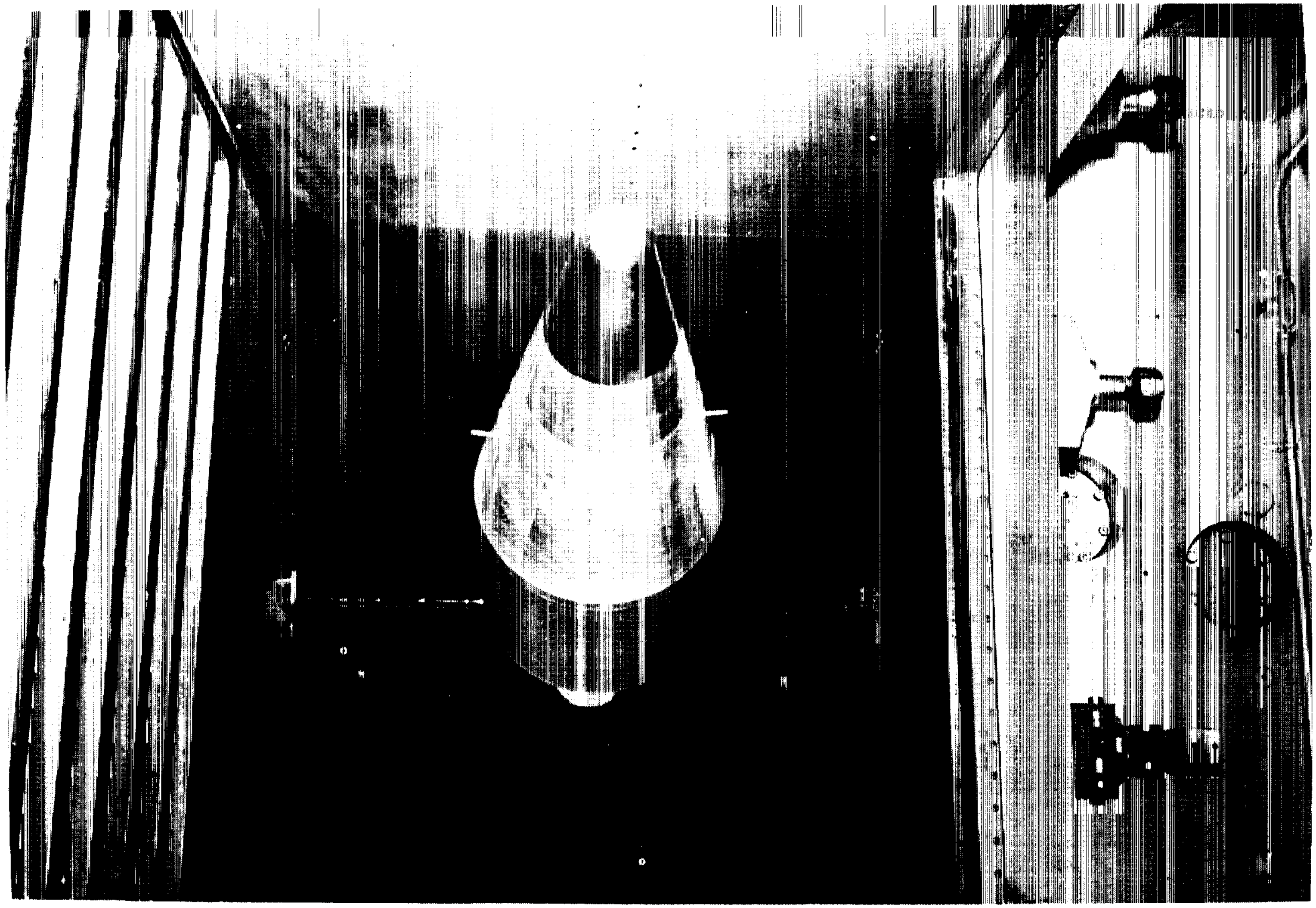
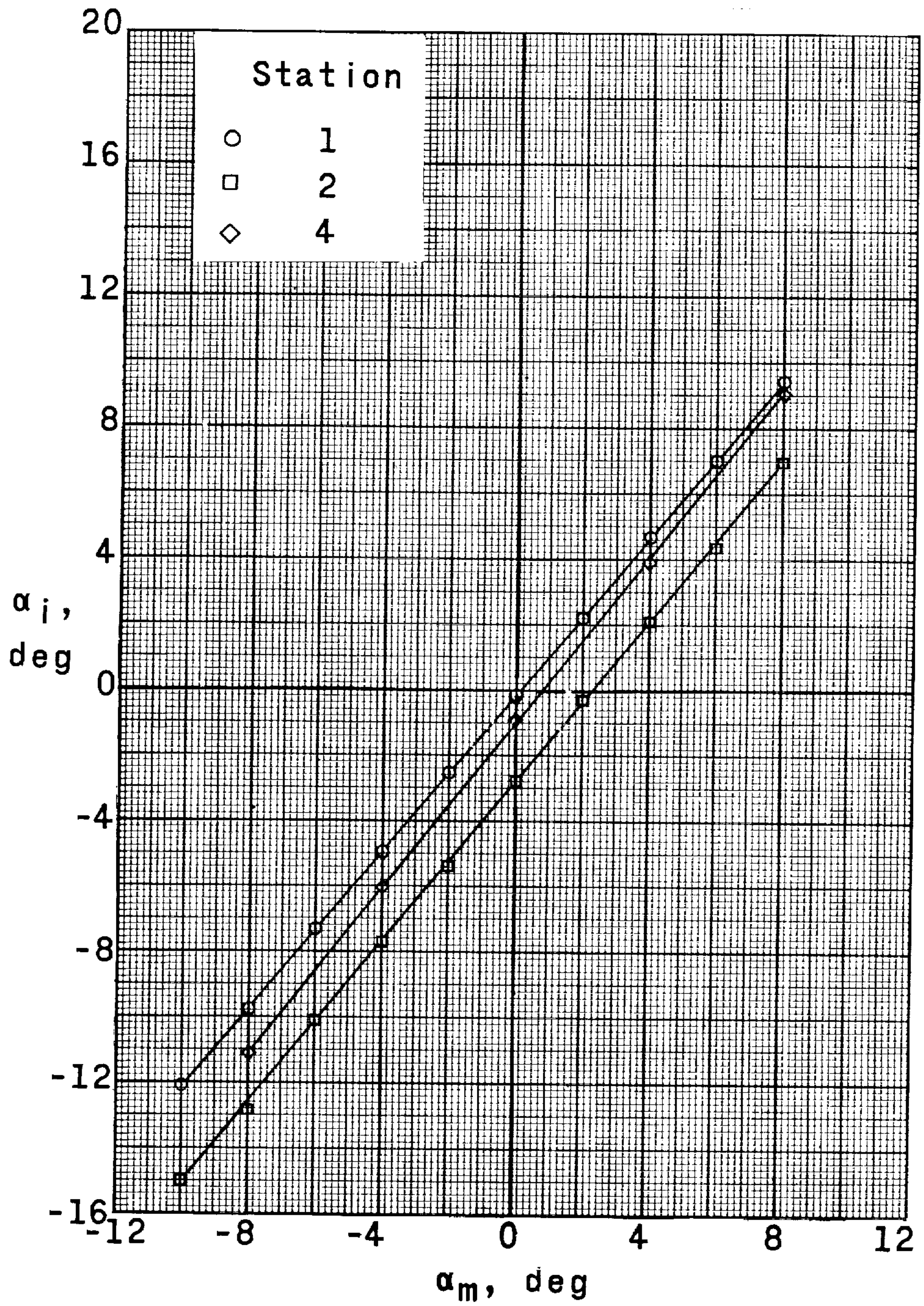
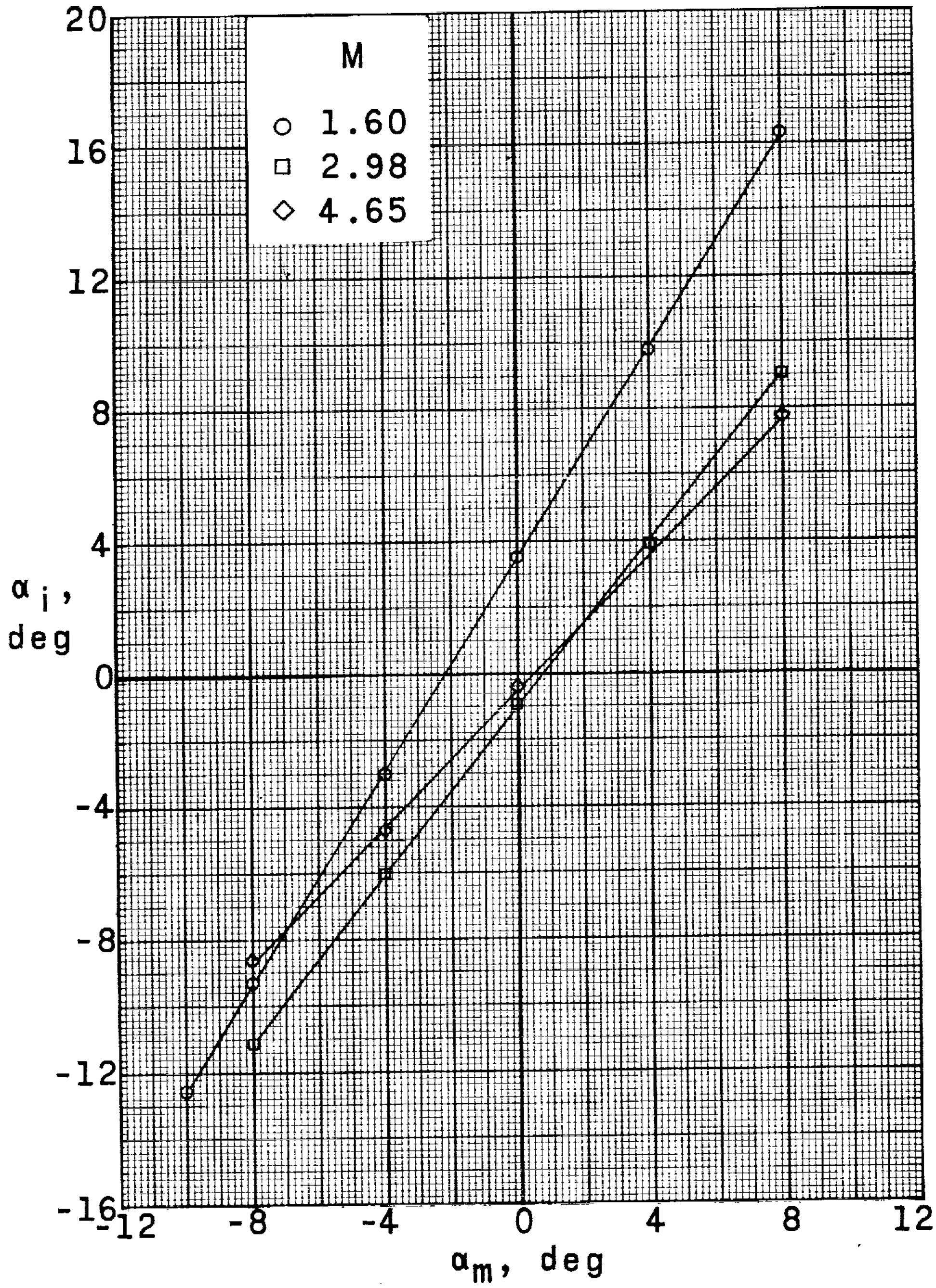


Figure 2.- Concluded. L-57-696



(a) M = 2.98.

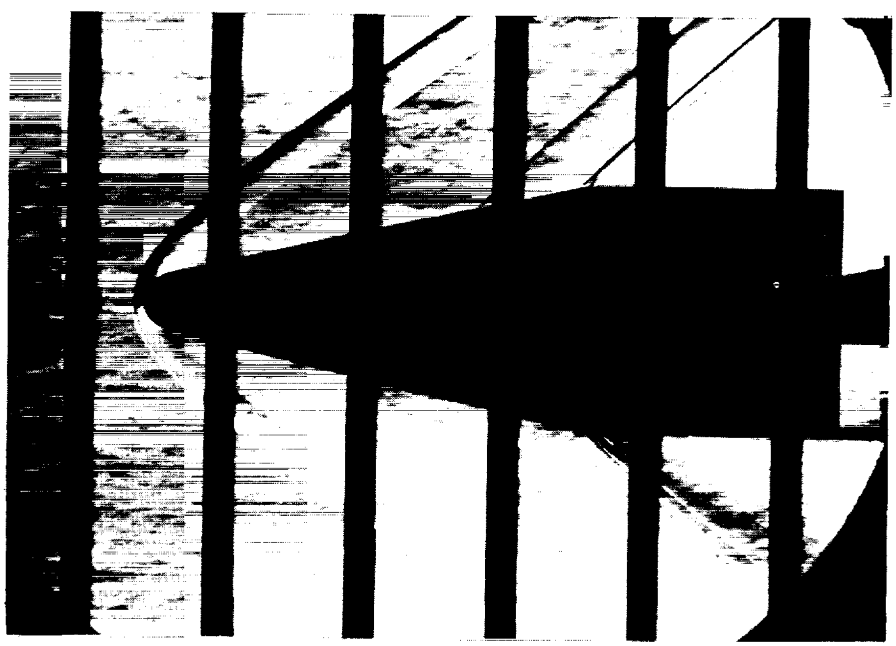
Figure 3.- Typical variations of local flow angle with model angle of attack. d = 0.75 inch; $\beta = 0^{\circ}$.



(b) Station 4.

Figure 3.- Concluded.

M = 1.60



M = 2.00

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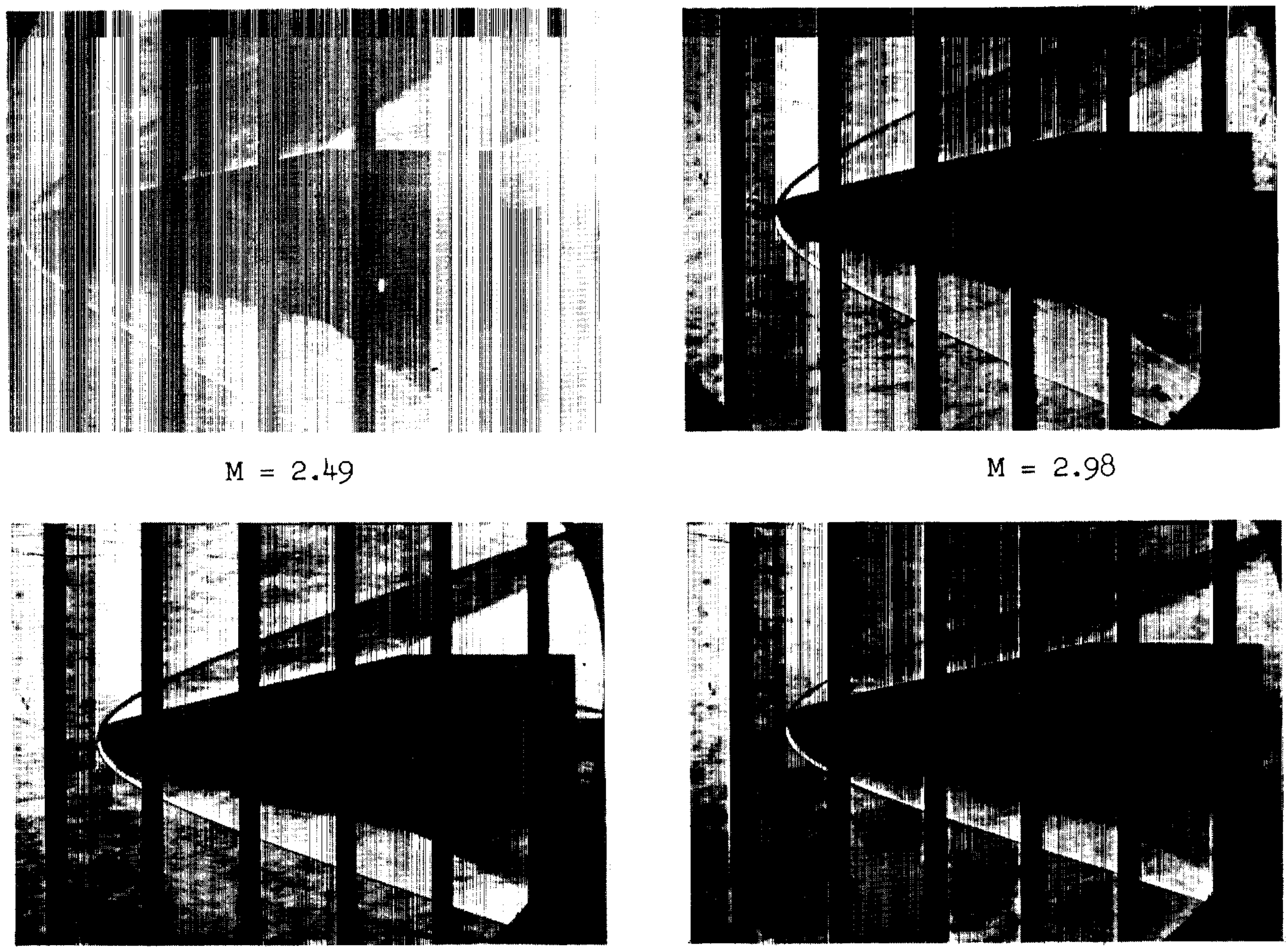
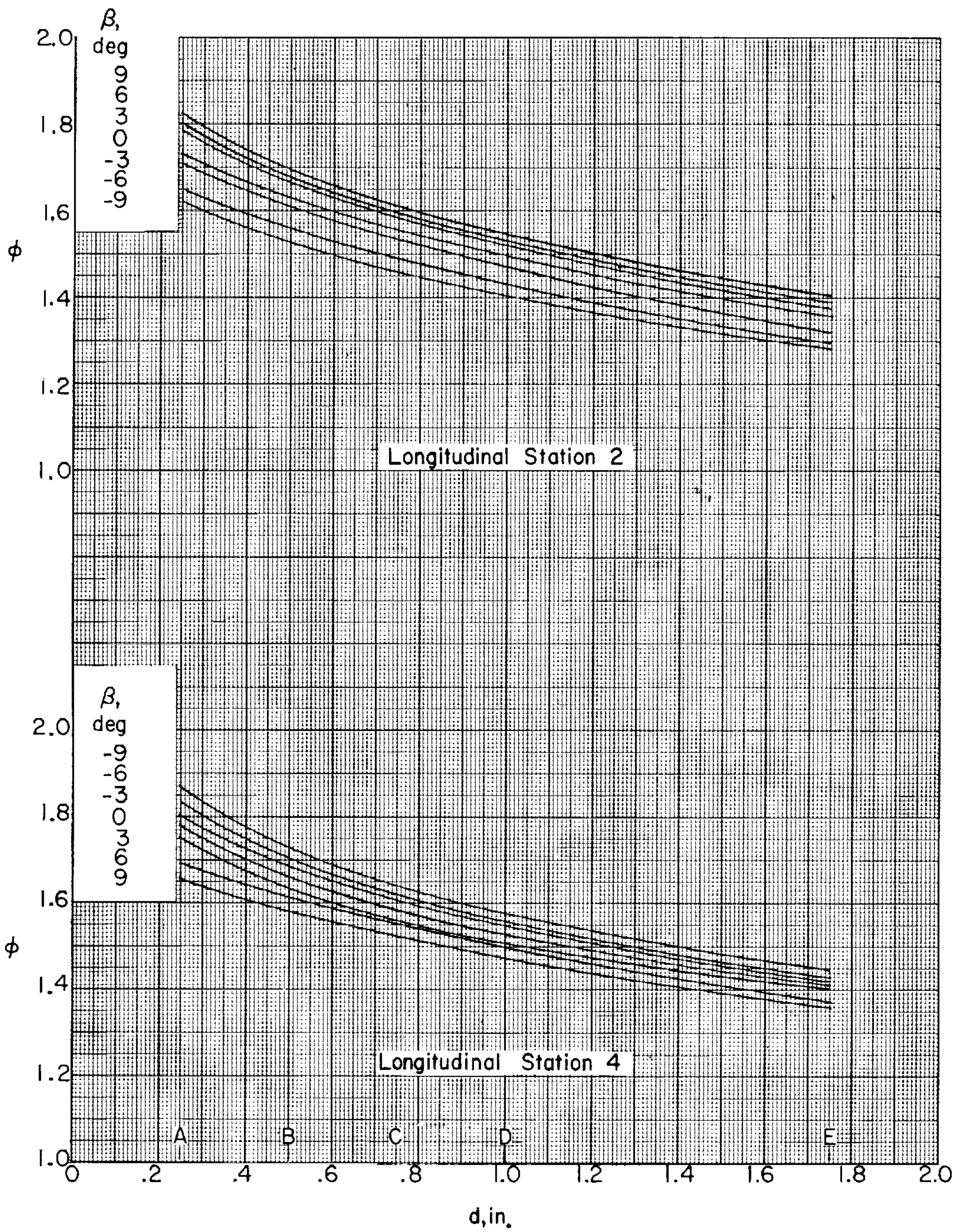
Figure 4.- Typical schlieren photographs of model. $\alpha_m = 0^\circ$; $\beta = 0^\circ$.



M = 2.49 M = 2.98

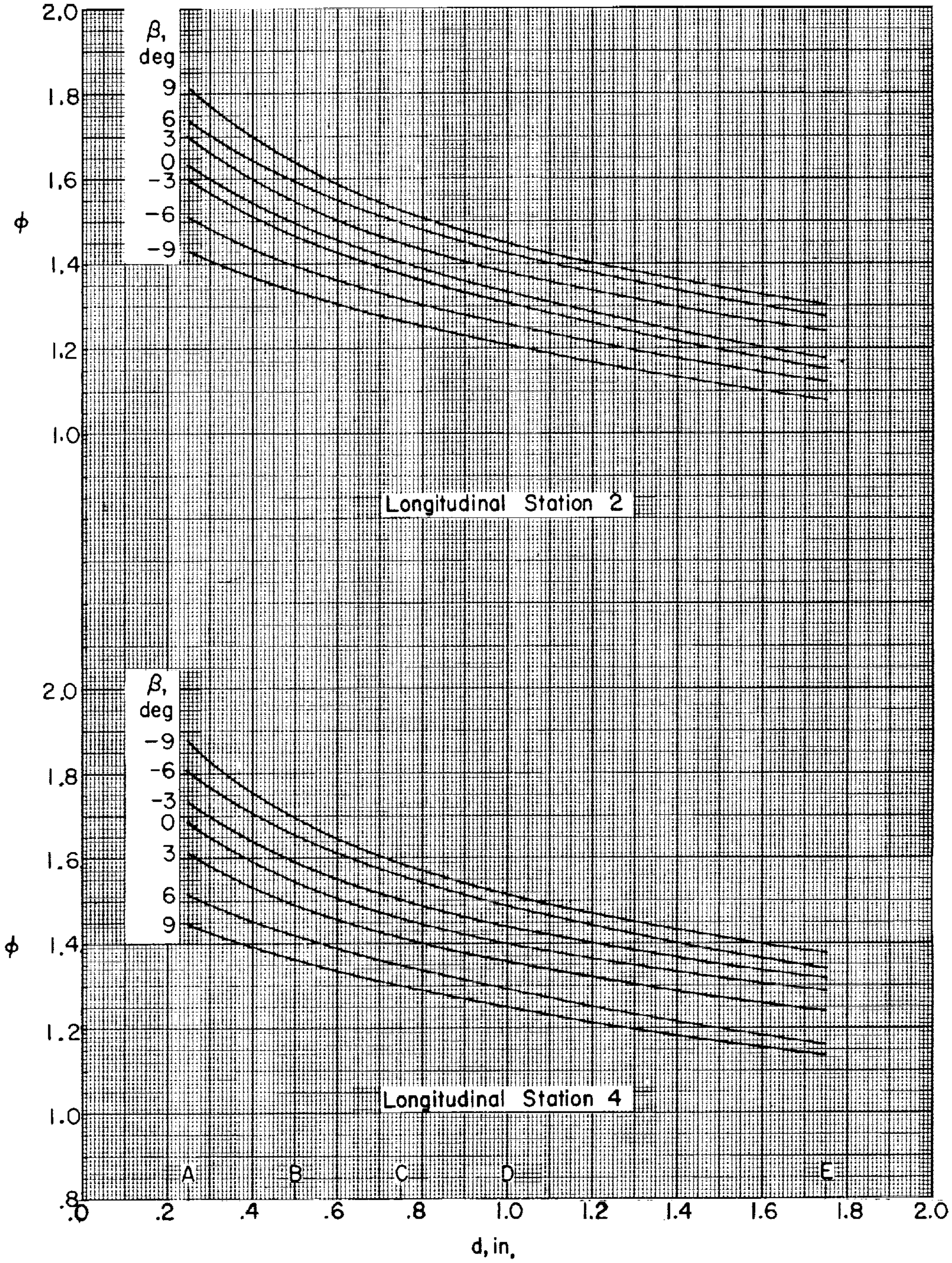
M = 3.83 M = 4.65 L-59-3016

Figure 4.- Concluded.



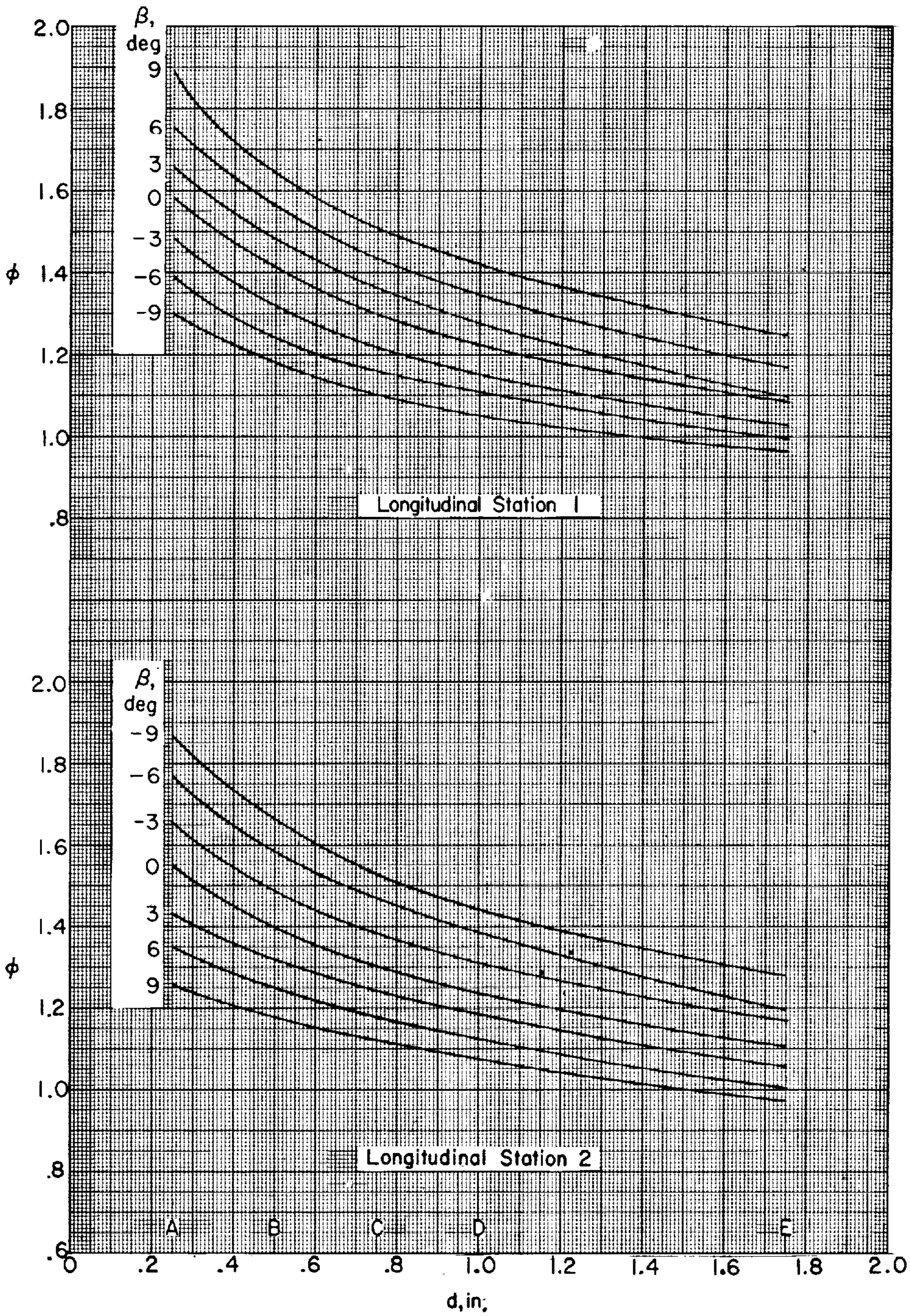
(a) M = 1.60.

Figure 5.- Variation of slope ϕ with probe outboard distance d at various longitudinal stations and for six Mach numbers. $\phi = \frac{d\alpha_i}{d\alpha_m}$.



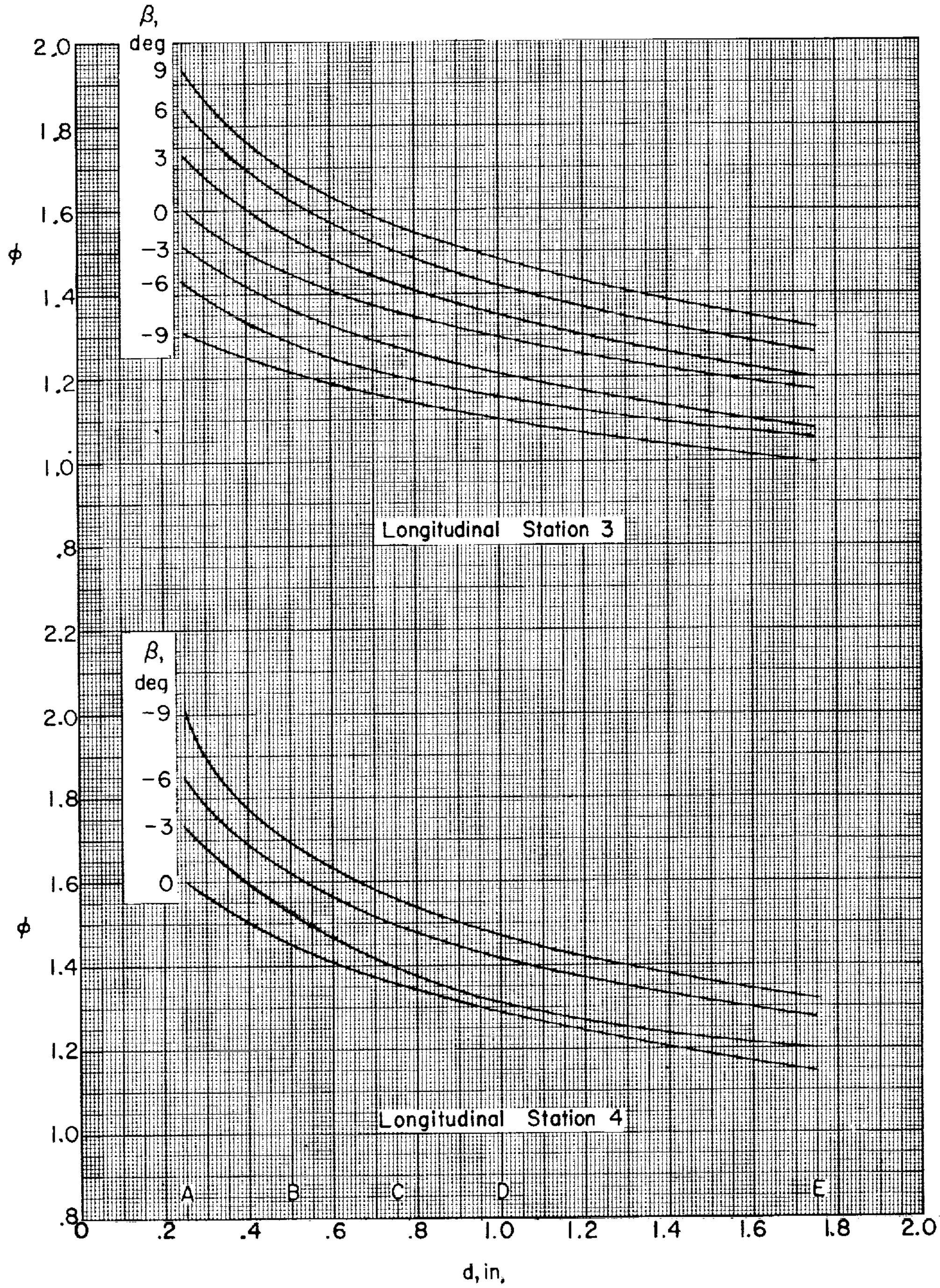
(b) M = 2.00.

Figure 5.- Continued.



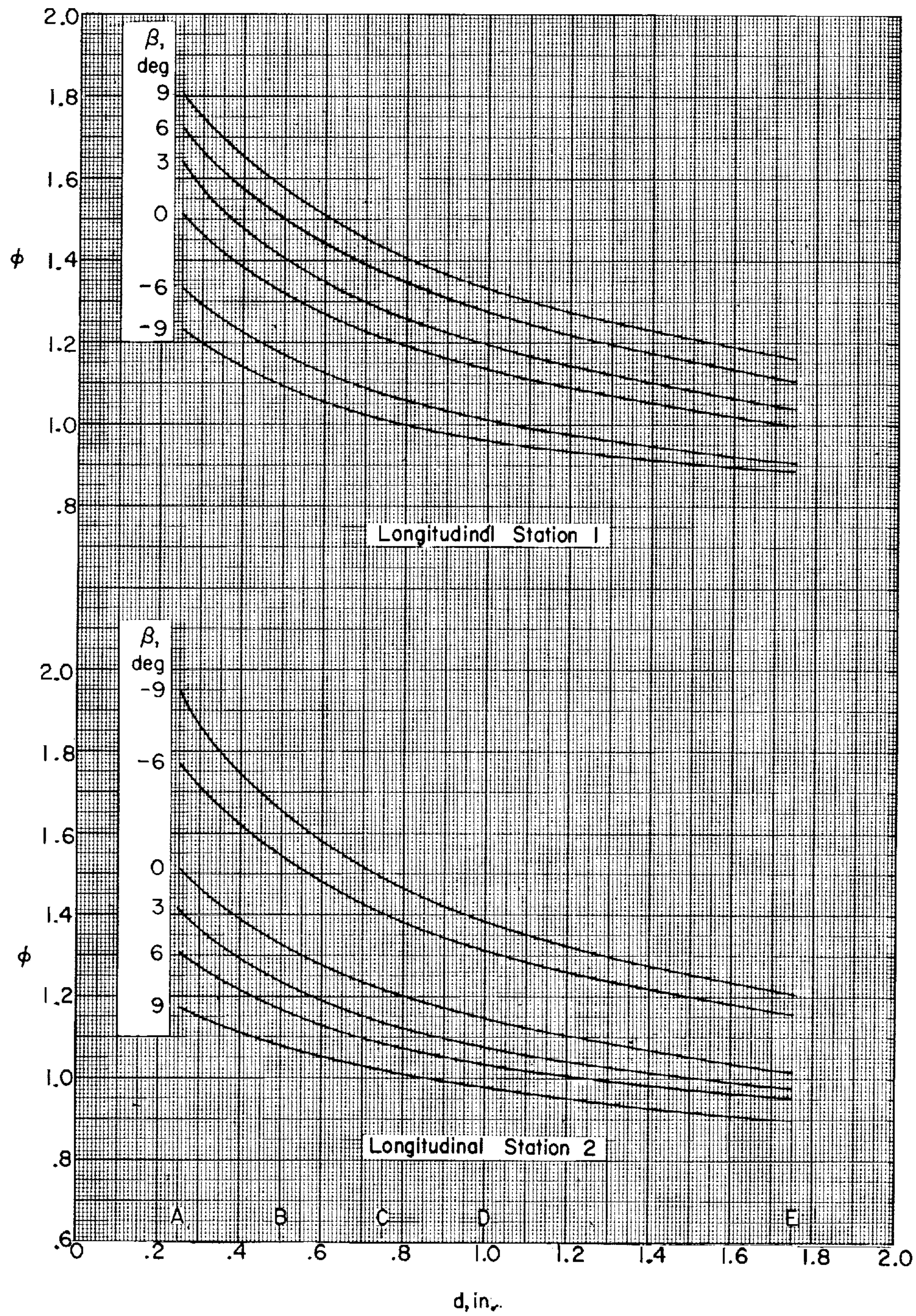
(c) M = 2.49.

Figure 5.- Continued.



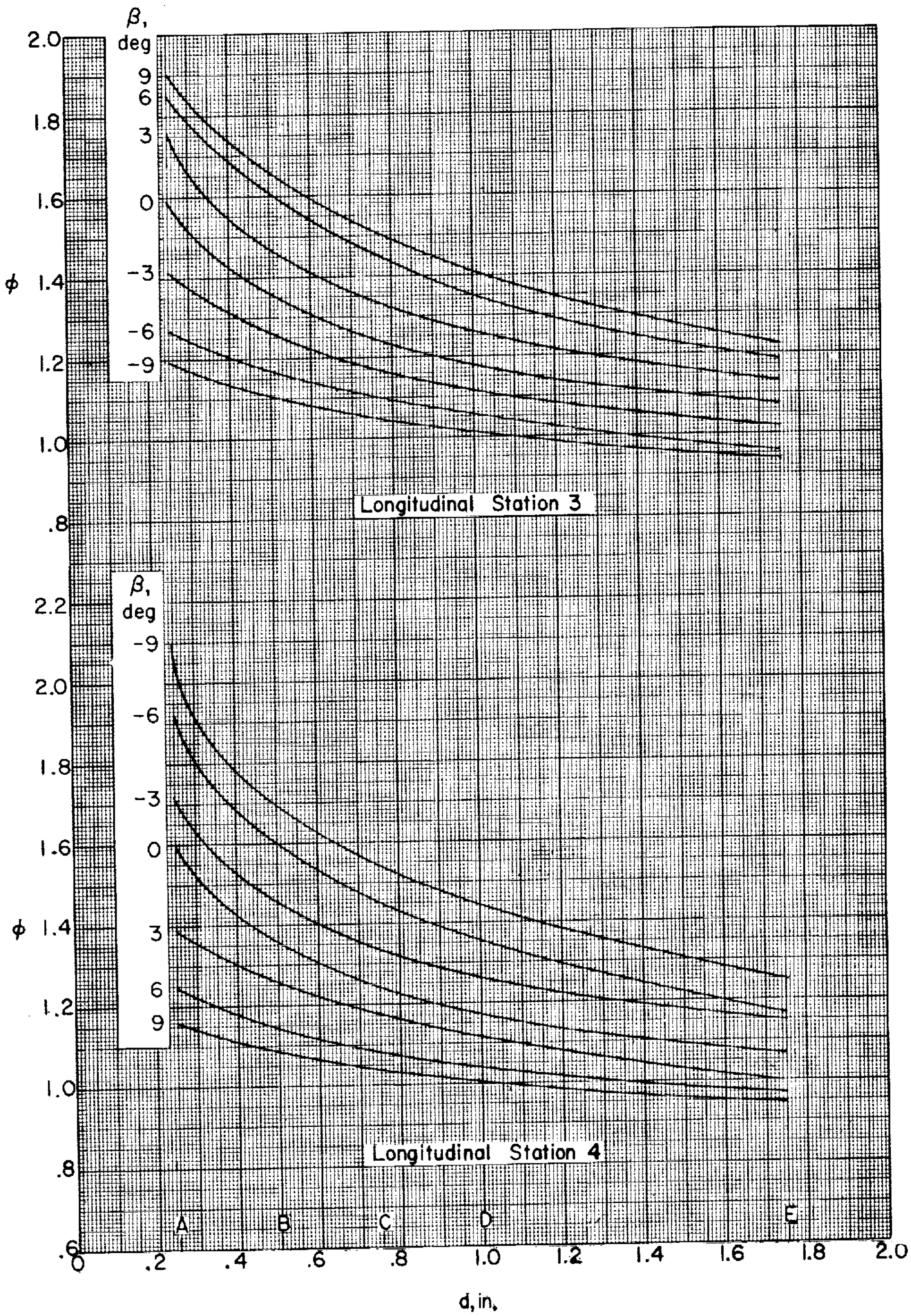
(c) Concluded.

Figure 5.- Continued.



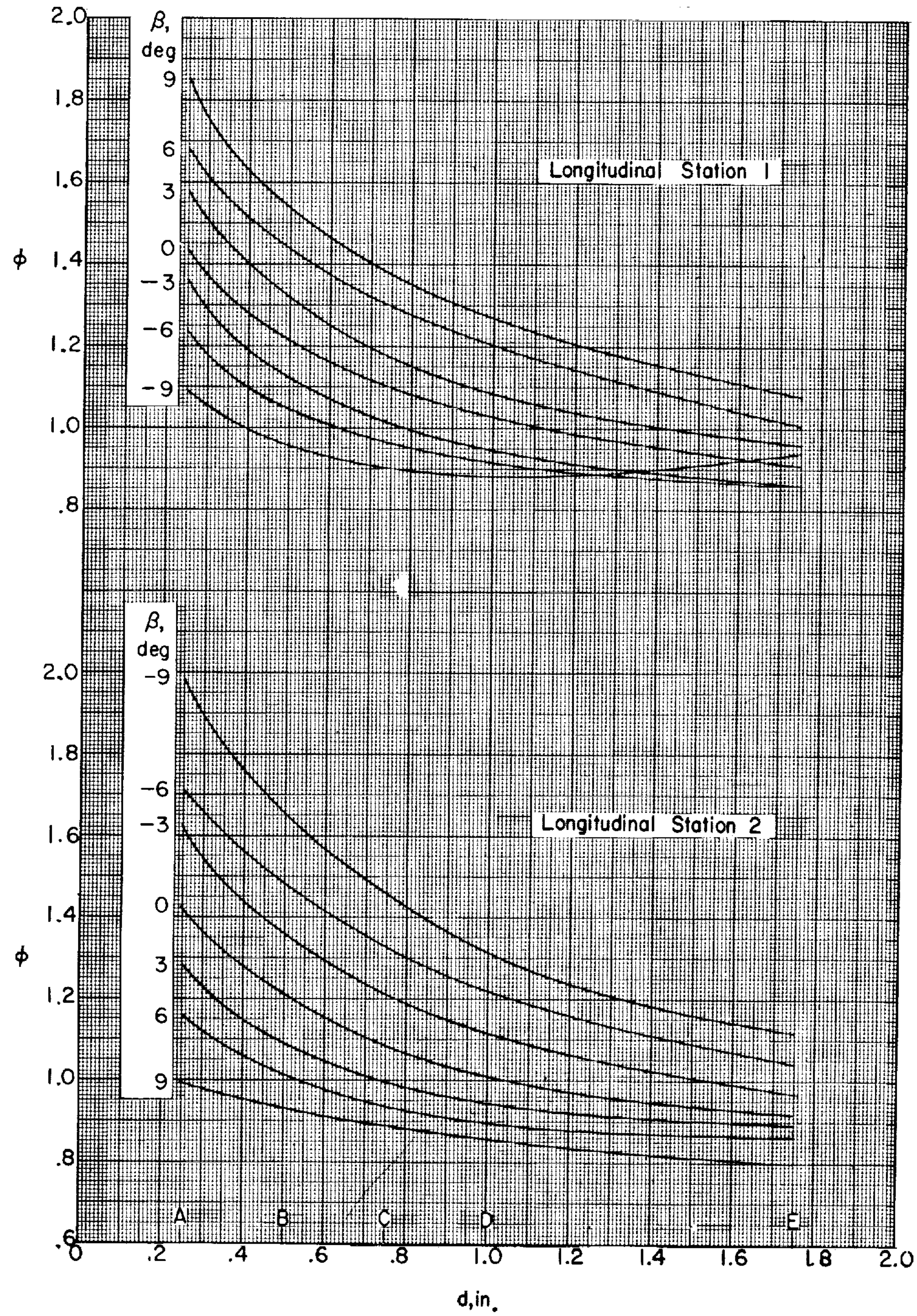
(d) M = 2.98.

Figure 5.- Continued.



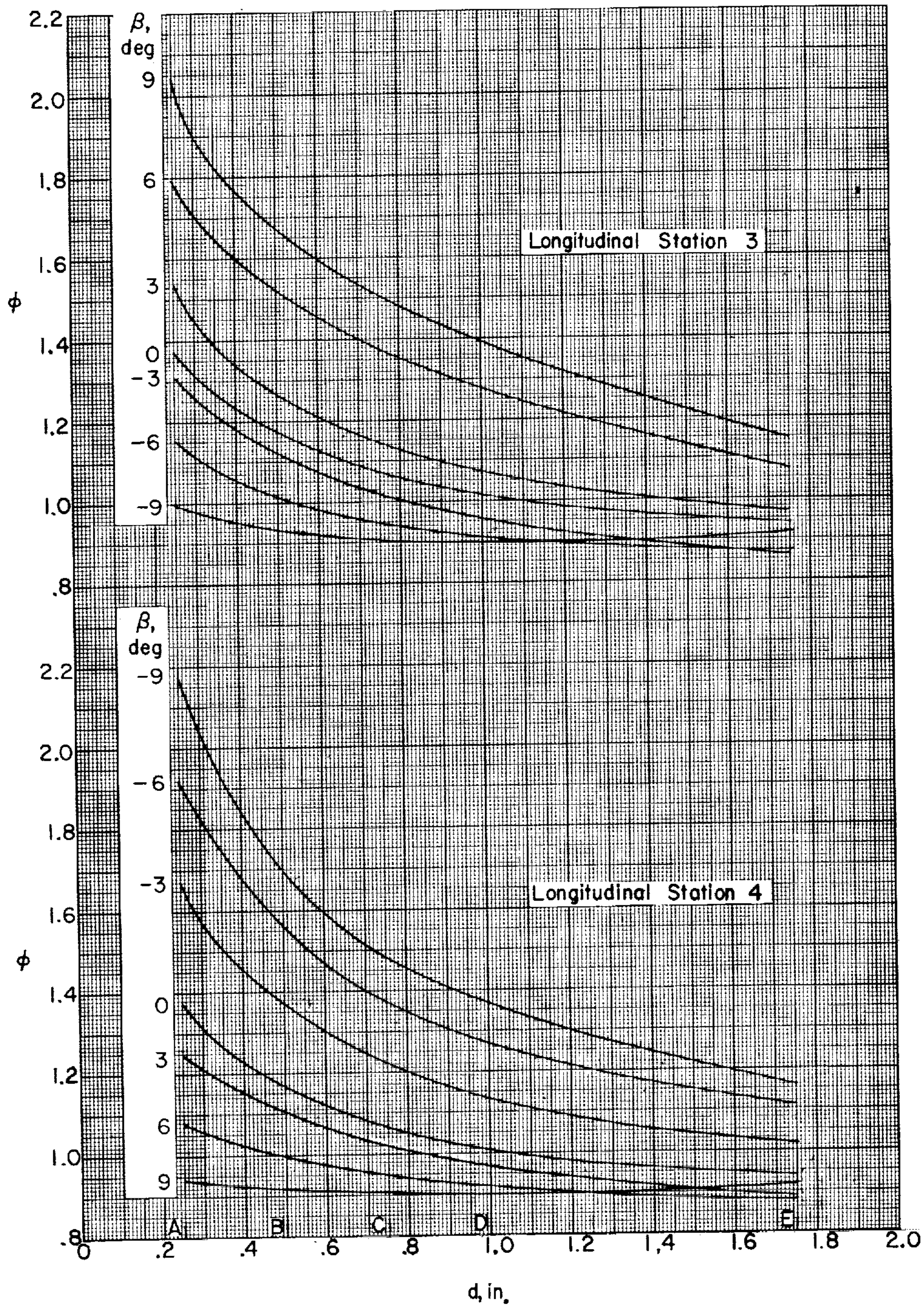
(d) Concluded.

Figure 5.- Continued.



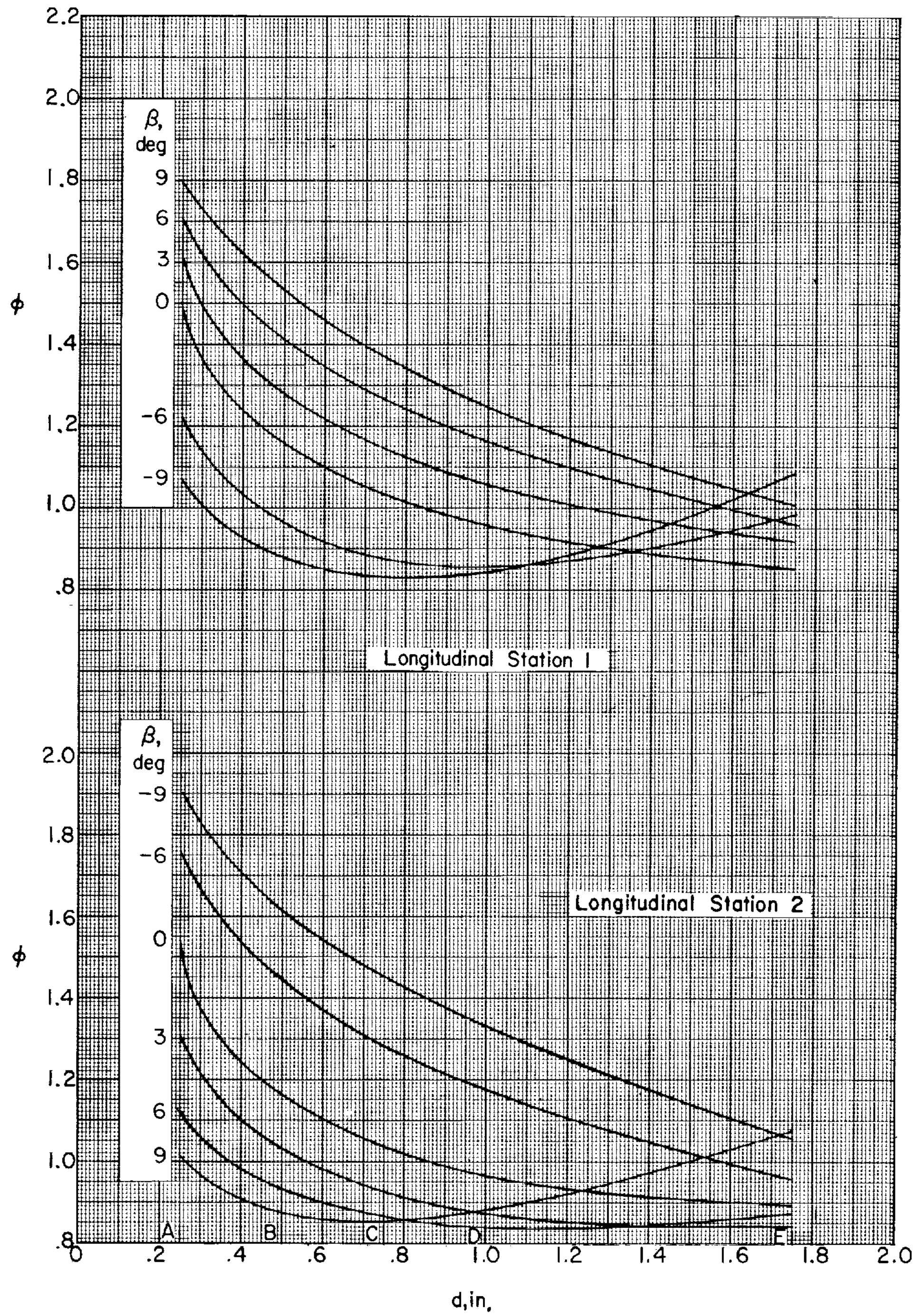
(e) M = 3.83.

Figure 5.- Continued.



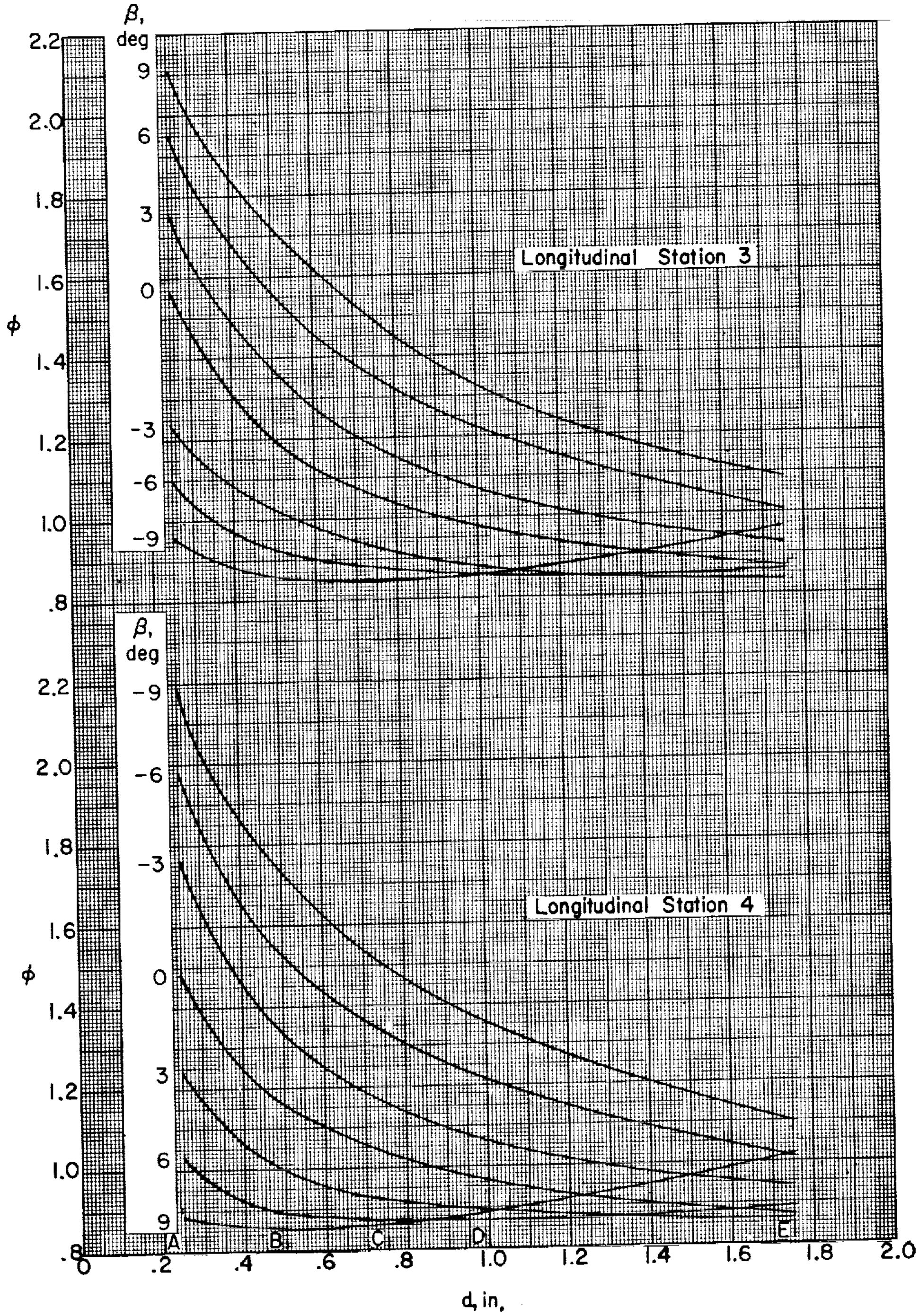
(e) Concluded.

Figure 5.- Continued.



(f) M = 4.65.

Figure 5.- Continued.



(f) Concluded.

Figure 5.- Concluded.

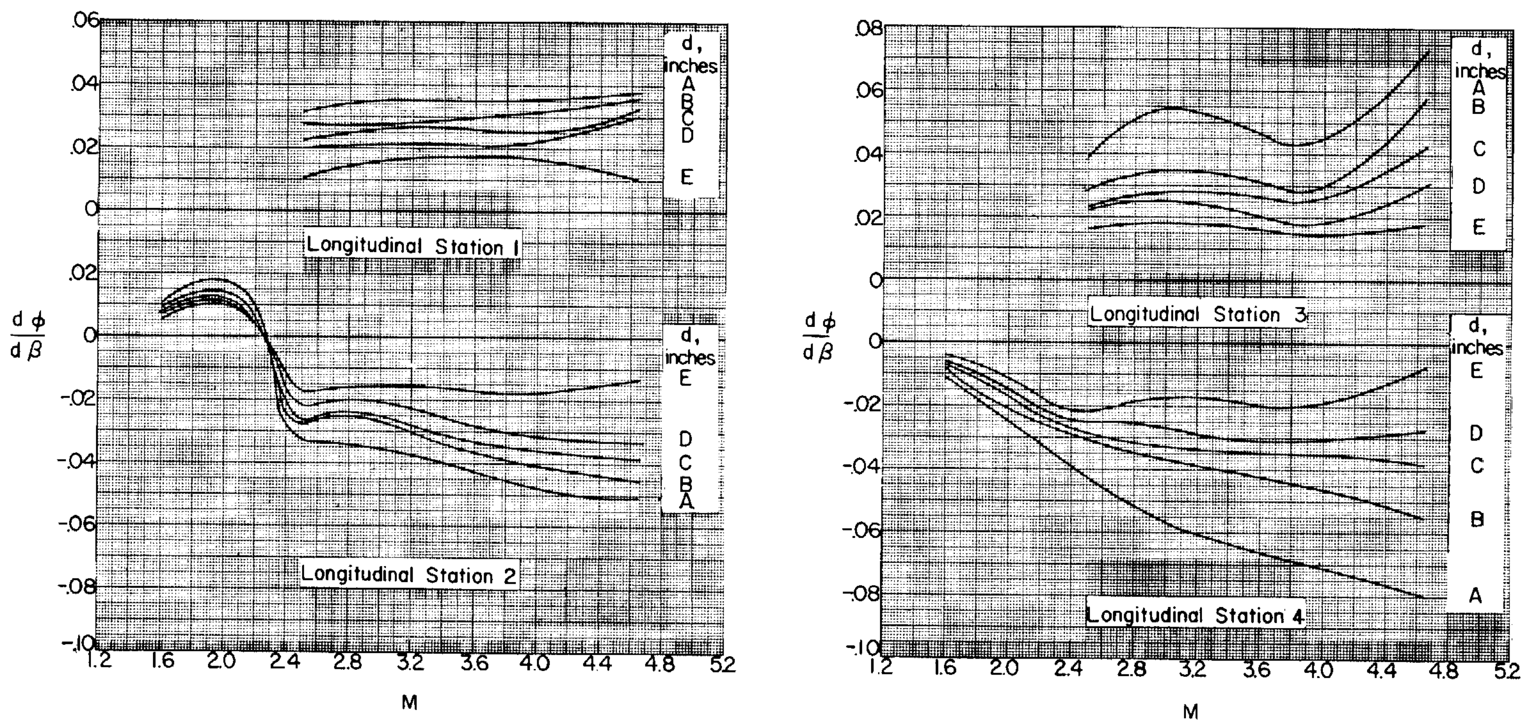


Figure 6.- Variation of $d\phi/d\beta$ with Mach number at various stations and for five probe outboard distances.